BCRRA 2022

Workshop: Managing Impact of Frost on Pavement Systems

Behavior of partially saturated asphalt concrete pavement under freezing and accelerated pavement testing conditions

Analysis of the structure response to thermal loading using FE modeling

Université Gustave Eiffel

UNIVERSITÉ LAVAL

i3c Phase 2

Chaire de recherche industrielle du CRSNG sur l'interaction charges lourdes-climat-chaussées

Computation of strains in L and T directions resulting from thermal loading

- Computations performed for the dry and partially saturated structure
- Use of the FE code developed in Vu’s thesis
- Problem complex to simulate → some adaptations to the initial script required to properly simulate the gage measurements
  - For the dry condition: friction conditions added at bottom of GB20

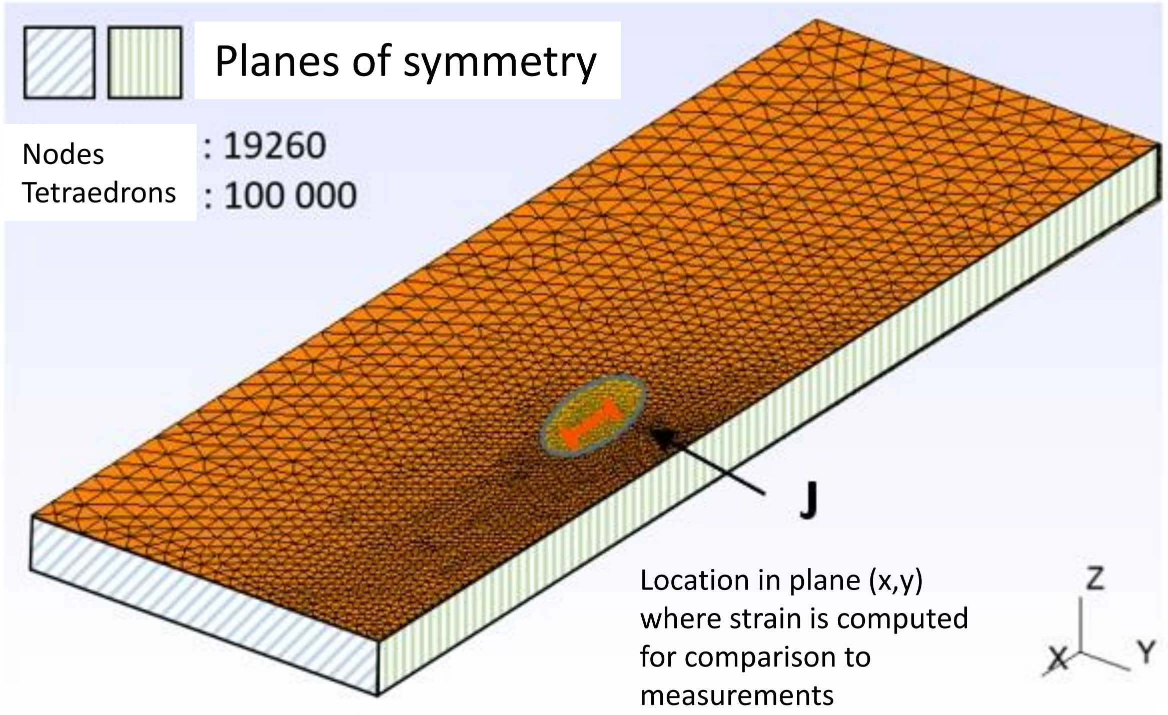
    Slow thermal loading induced a low apparent modulus of the AC materials ; the structural anisotropy observed under thermal loading can results from friction conditions (e.g. Coulomb’s friction law under normal stress due to own weight) at bottom of the AC layers (bottom of GB20) that lead to different effects in the L and T directions because of significant difference in length of the pit in these directions

  - For the partially saturated condition: Friction conditions at the interface between the bituminous layers introduced + friction conditions kept at bottom of GB20

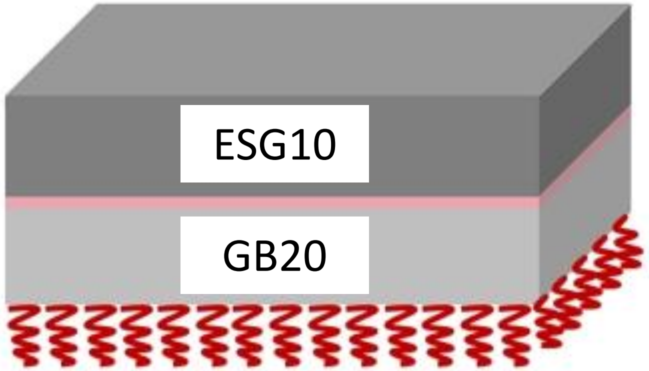
FE modeling of the structure response under thermal loading

- The 2 bituminous layers are meshed considering 3D finite elements
- The vertical stiffness of the overall granular layers is represented by Winkler's springs ($\sigma_{zz} = K_{soil} u_z$ with K_{soil} backcalculated from deflection under wheel load)

Top view of the AC layers mesh



Reaction forces of unbound layers as boundary conditions through springs



K_{soil}

FE modeling of the structure response under thermal loading (cont.)

- Contact conditions in the horizontal directions at bottom of GB20 modeled using Winkler's springs in directions L and T leading to the following relationships (between shear stress and horizontal displacement):

$$\begin{cases} \sigma_{xz} = -K_f U_x \\ \sigma_{yz} = -K_f U_y \end{cases}$$

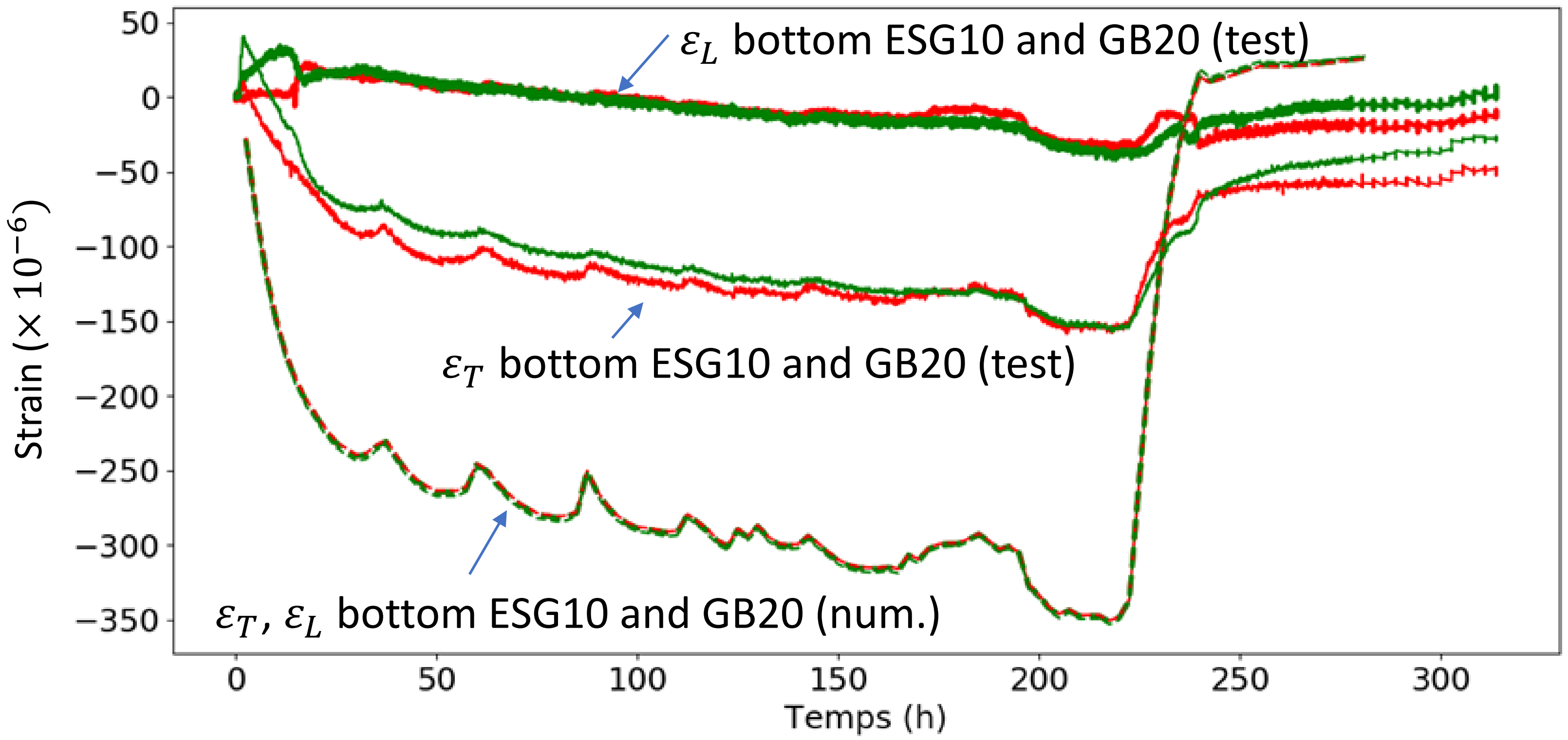
K_f value is use to represent friction in a approximative way (Coulomb's friction law would be more appropriate but non linear problem)

→ $K_f = 0$ no friction otherwise $K_f = 1.32\ MPa/mm$ (backcalculated)

In addition for the partially saturated condition:

- friction conditions (partial sliding) between the 2 AC layers introduced by using horizontal « nodal » springs at this interface – friction law (not purely elastic) approached considering incremental elasticity and spring stiffness varying with time (in the course of thermal loading)
- $\varepsilon_g \approx 300\ \mu strain$ from CTFS tests carried out on ESG10

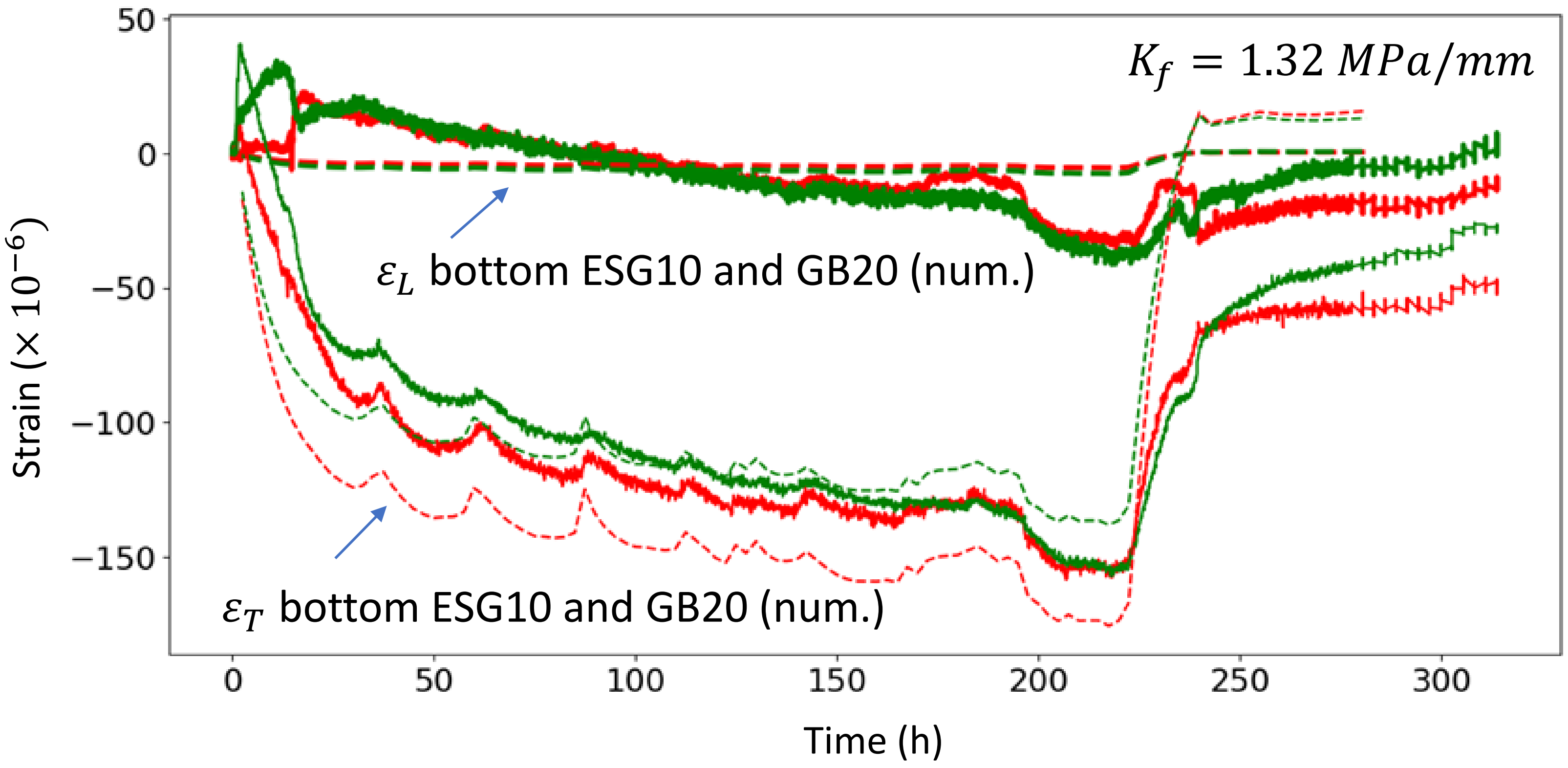
Strain computations w/o friction at bottom of GB20 ($K_f = 0$) and comparison with gage measurements (dry condition)



Computations for $K_f = 0$ (temperature from 5 to -10 to 5°C)

- Same strain values in directions L and T in contrast to measurements → structural anisotropy observed in the measurements not well reproduced
- Strain magnitude too high compared to measurements (which is almost zero in direction L)

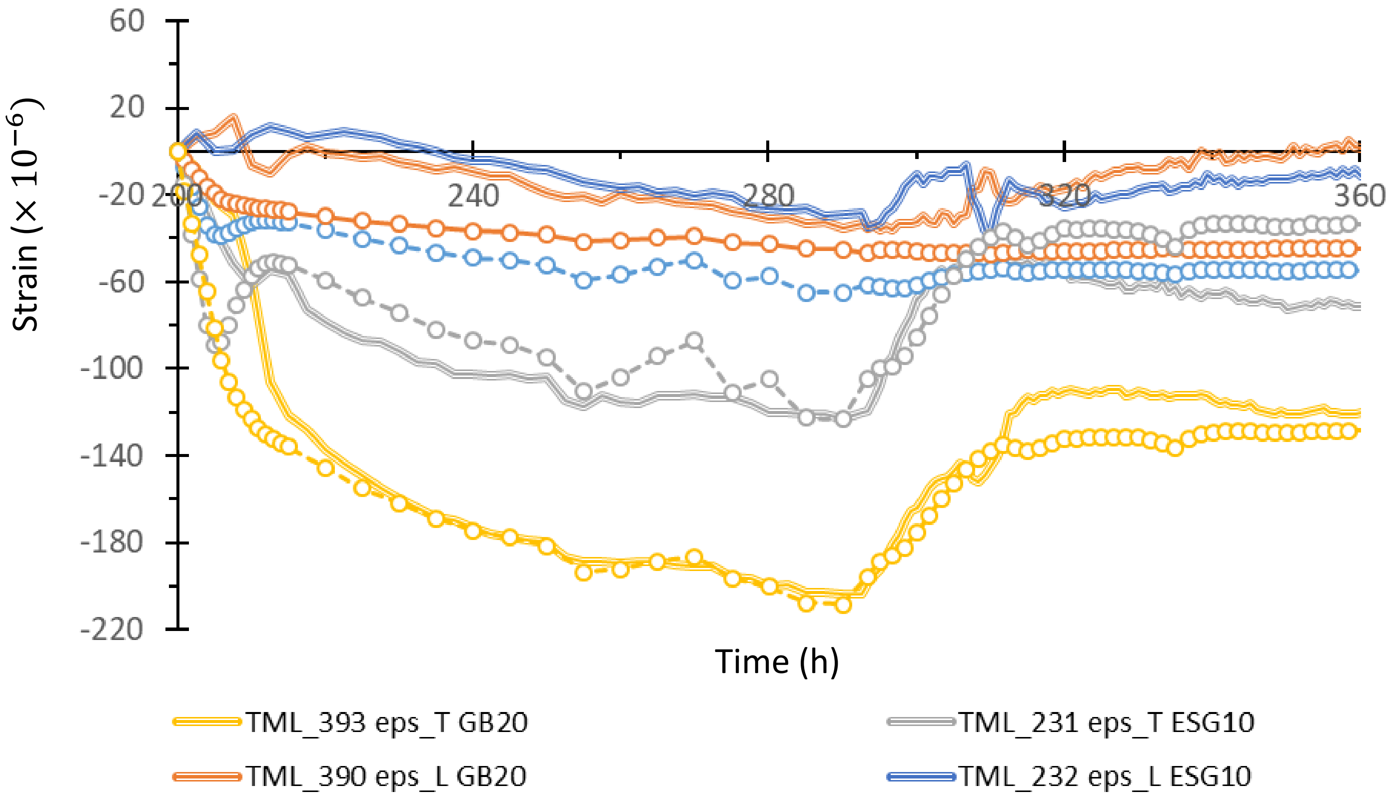
Strain computations w/ friction at bottom of GB20 and comparison with gage measurements (dry condition)



Computations for $K_f = 1.32\ MPa/mm$ (horizontal springs at bottom of GB20)

- The computed strains are close to the gage measurements – the friction conditions at bottom of GB20 induce very low strain in direction L as observed in the measurement
- The simulation now accounts for the structural anisotropy observed in the test
- The assumptions of this computation are kept for the following simulations of the partially saturated structure

Partially saturated condition: strain computation and comparison with gage measurements (final modeling)



- Quite good agreement between the measurements and simulations for the calibrated model considering all the phenomena involved
- Transversal strains different at bottom of ESG10 and GB20 (in contrast to dry conditions) → In the computation: partial sliding at interface between the 2 AC layers + swelling strain in the partially saturated ESG10
- Longitudinal strains quite similar at bottom of ESG10 and GB20 and of smaller magnitude than in direction T (friction at bottom of GB20)

Thank you for your attention!

olivier.chupin@univ-eiffel.fr

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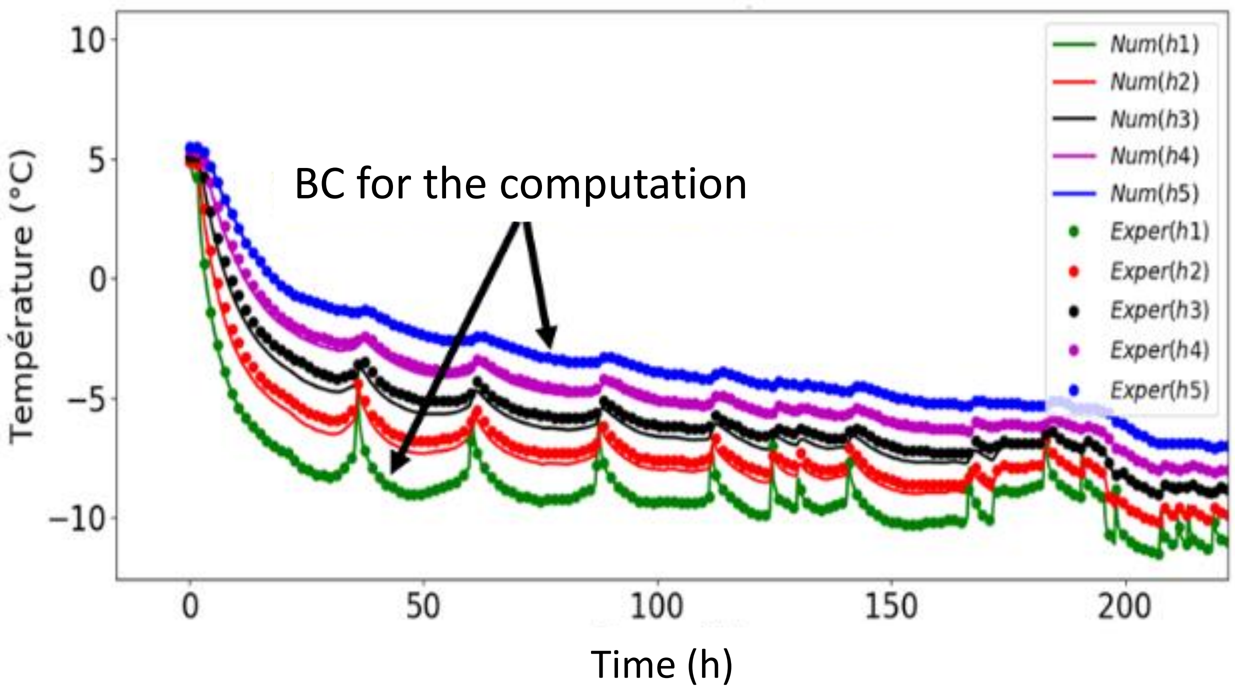
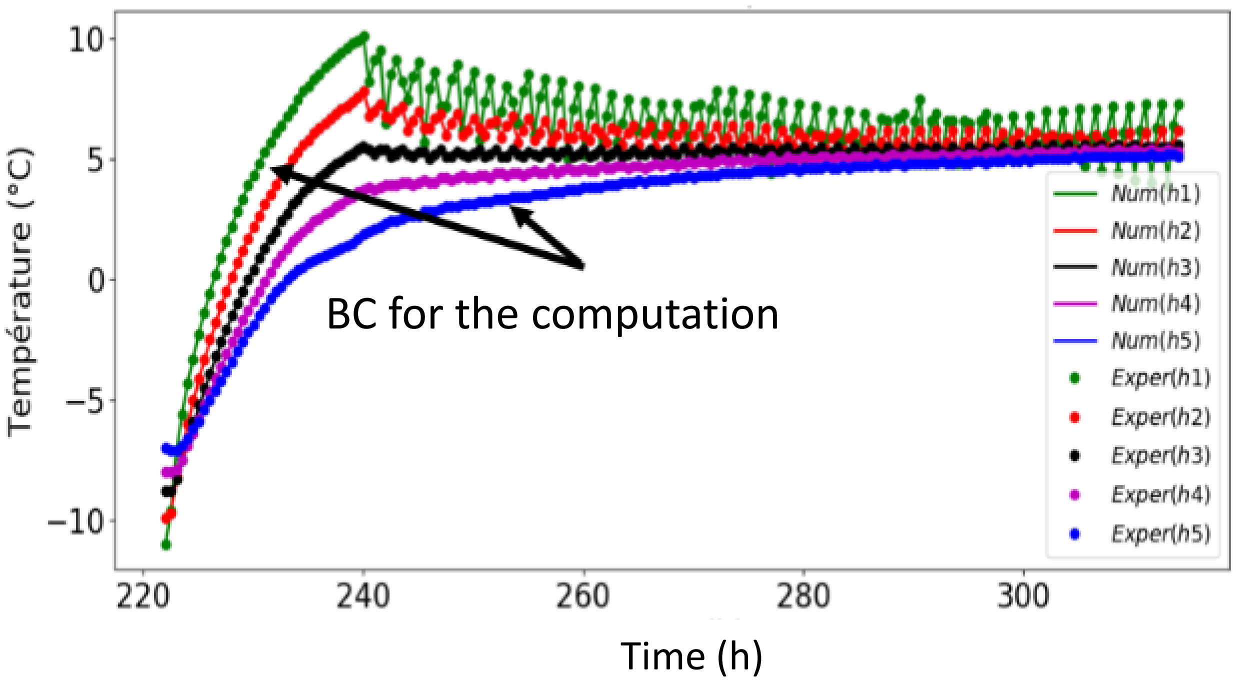
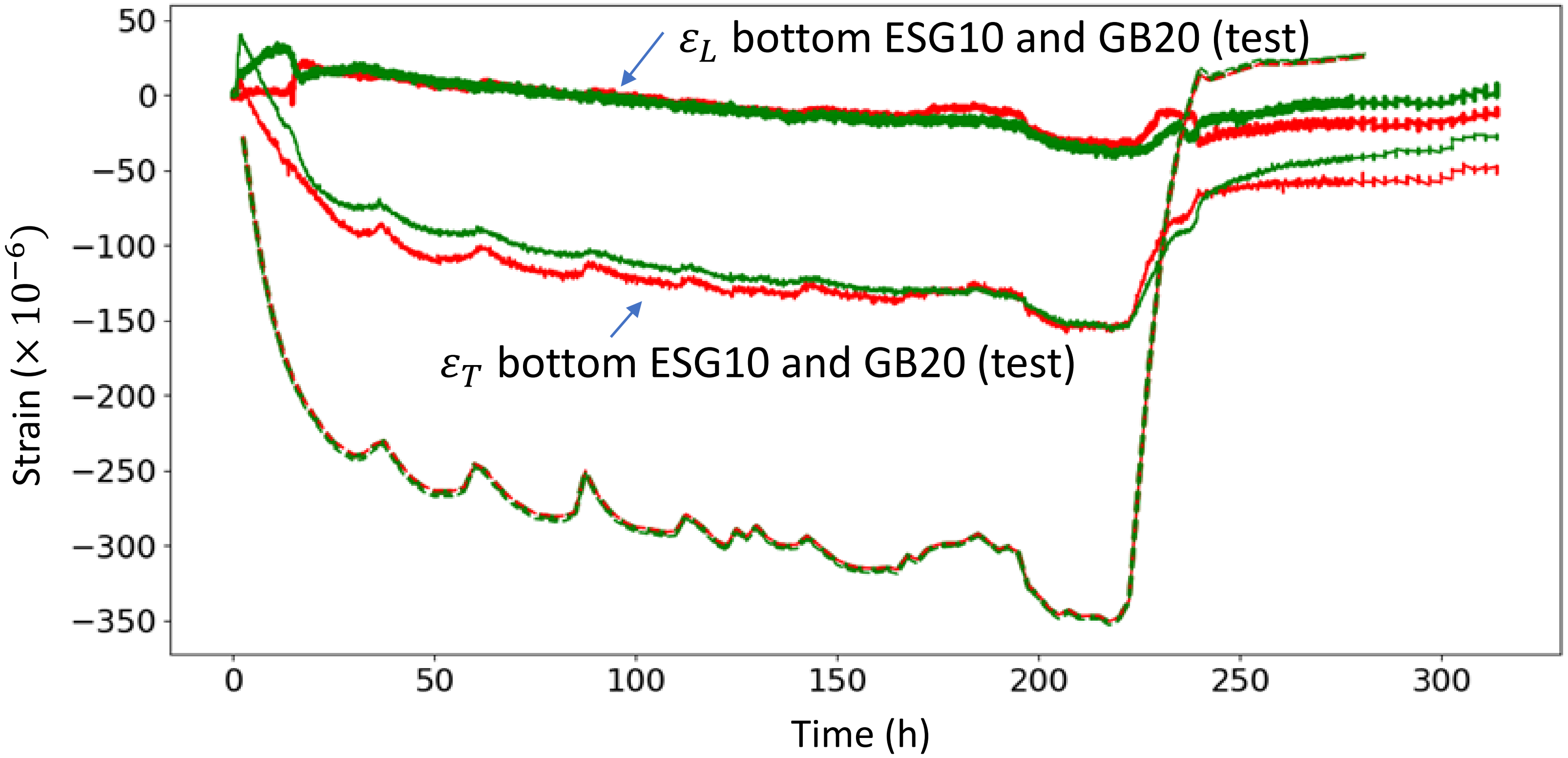
A typical temperature cycle applied to the structure (between +5°C and -10°C) and the resulting temperature gradient in the AC layers



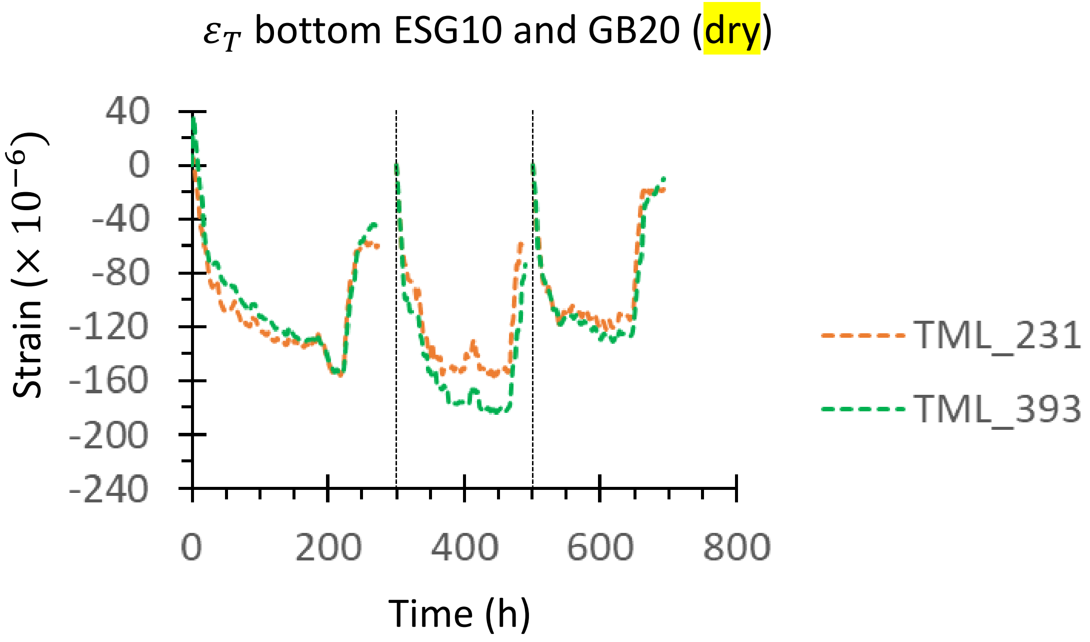


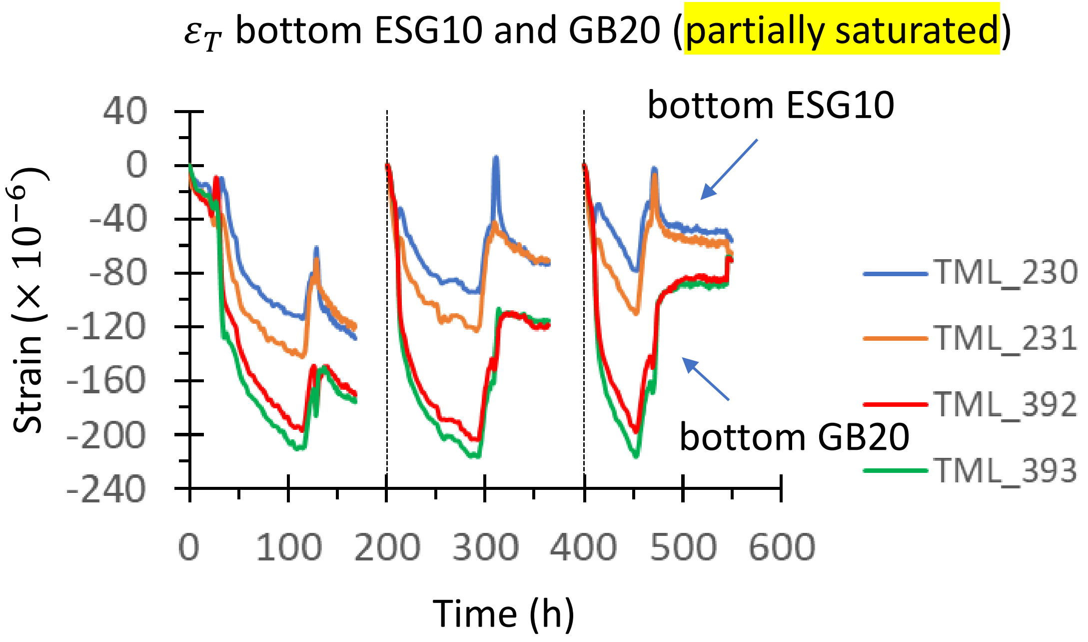
Evolution of strains at bottom of ESG10 and GB20 in directions L and T: gage measurements over a temperature cycle



- Measured strains globally in contraction (<0) in both directions
- Strains at bottom of ESG10 close to those at bottom of GB20 in directions L and T (no global bending of the bituminous layers despite the thermal gradient in the structure)
- ε_T higher than ε_L → reflects structural anisotropy attributed to friction at bottom of GB20 different in the L and T directions and arising for the "slow" thermal loading. This effect, largely pronounced in direction L, considerably limits deformation of the structure in this direction

Experimental facts: transversal strain at bottom of ESG10 and GB20

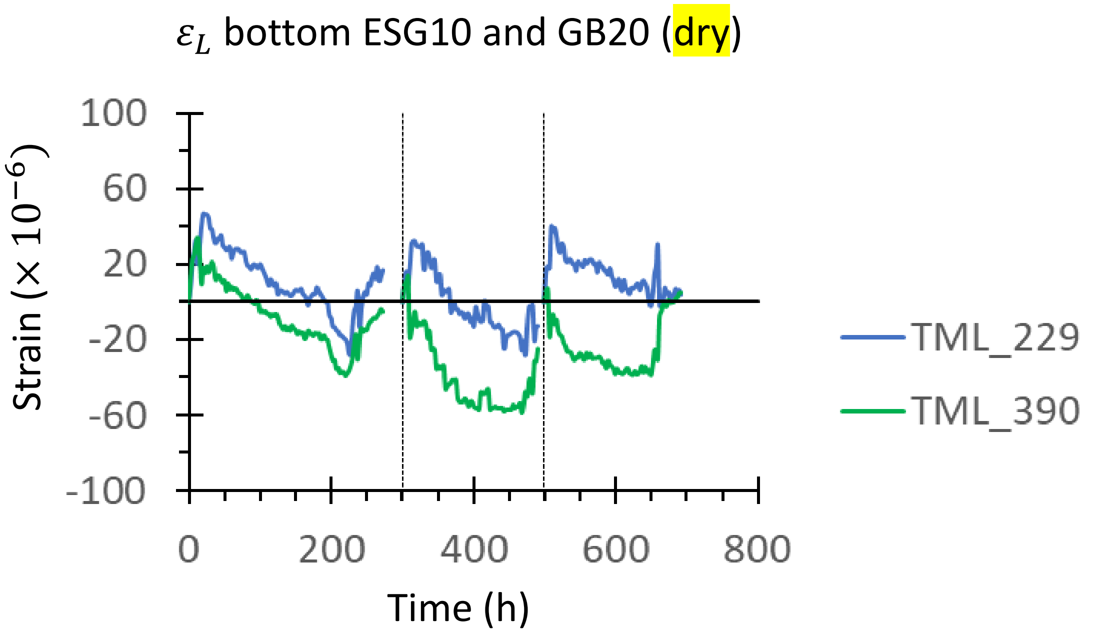


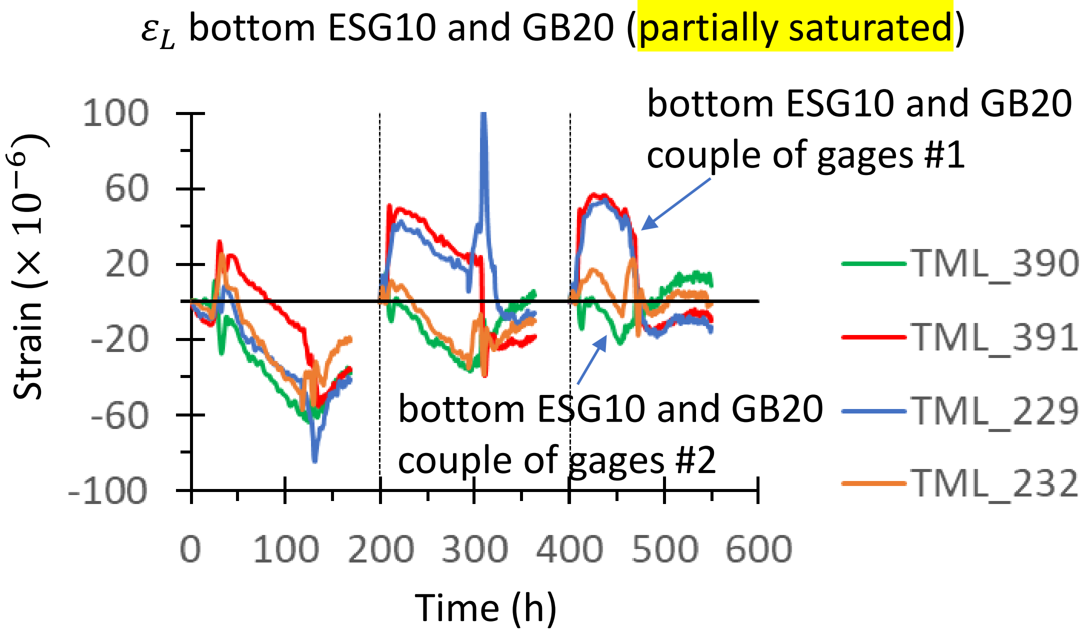


About the partially saturated structure (figure on right)

- Strains measured by different gages located at same depth in the AC layers quite similar
- Good repetition of the response along the 3 temperature cycles
- In contrast to the response under dry conditions: difference in the transversal strains measured at bottom of ESG10 and GB20 → diminishing the friction properties between the AC layers and introducing a swelling strain in the model

Experimental facts: longitudinal strain at bottom of ESG10 and GB20

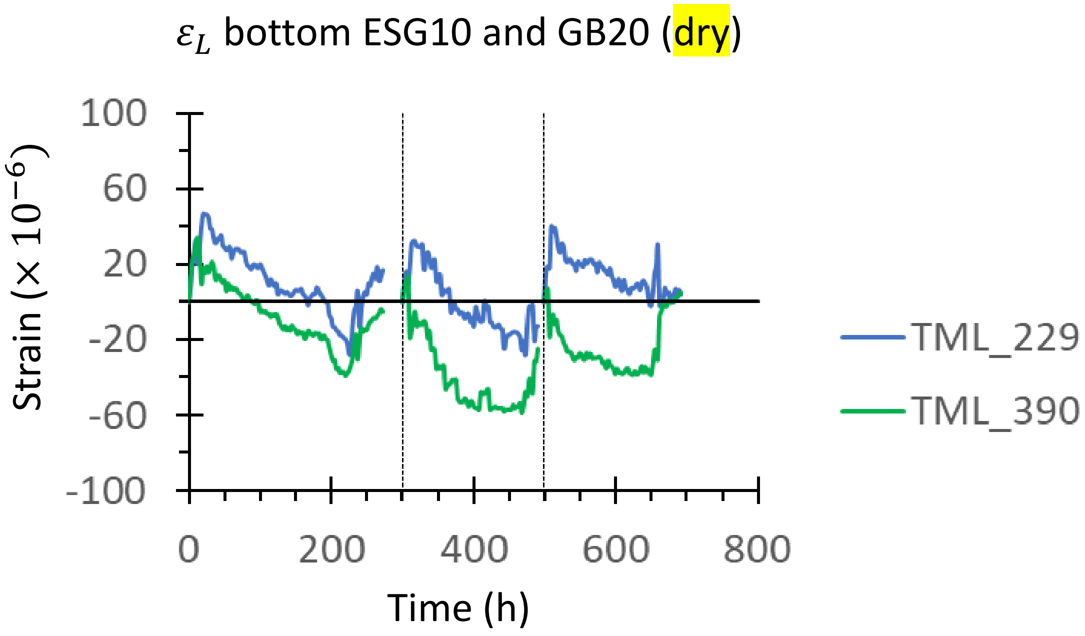


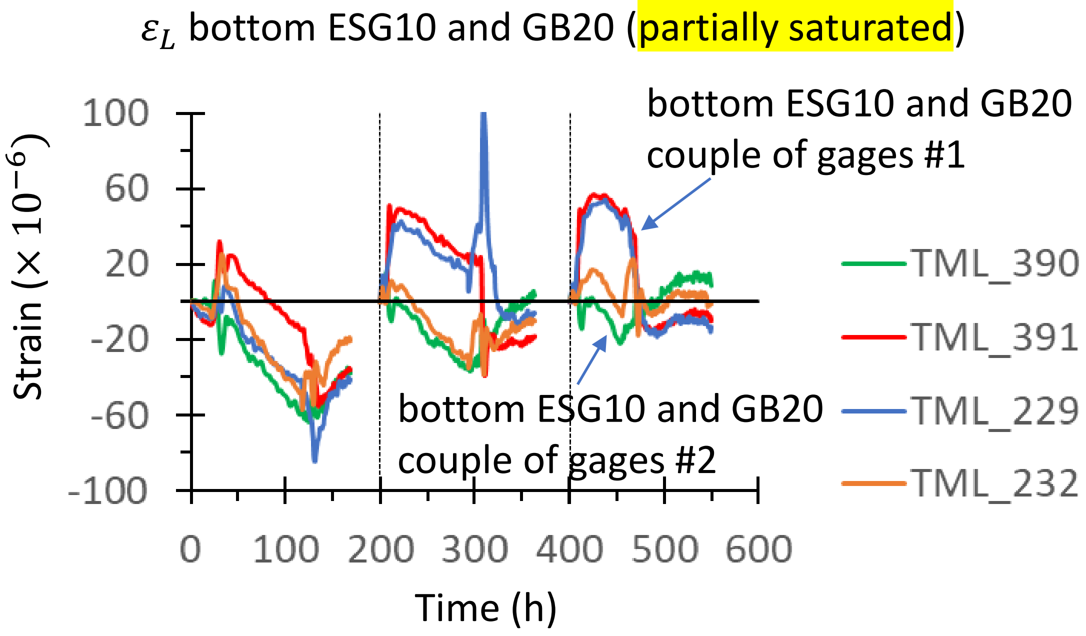


About the partially saturated structure (figure on right)

- Longitudinal strains smaller than transversal ones but of significant values
- For a given couple of gages, longitudinal strain measured at bottom of ESG10 and GB20 similar → keeping with "strong" friction conditions at bottom of GB20

Experimental facts: longitudinal strain at bottom of ESG10 and GB20 (cont.)



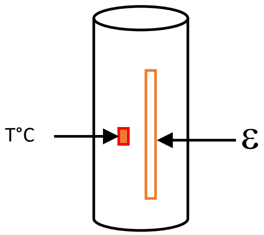


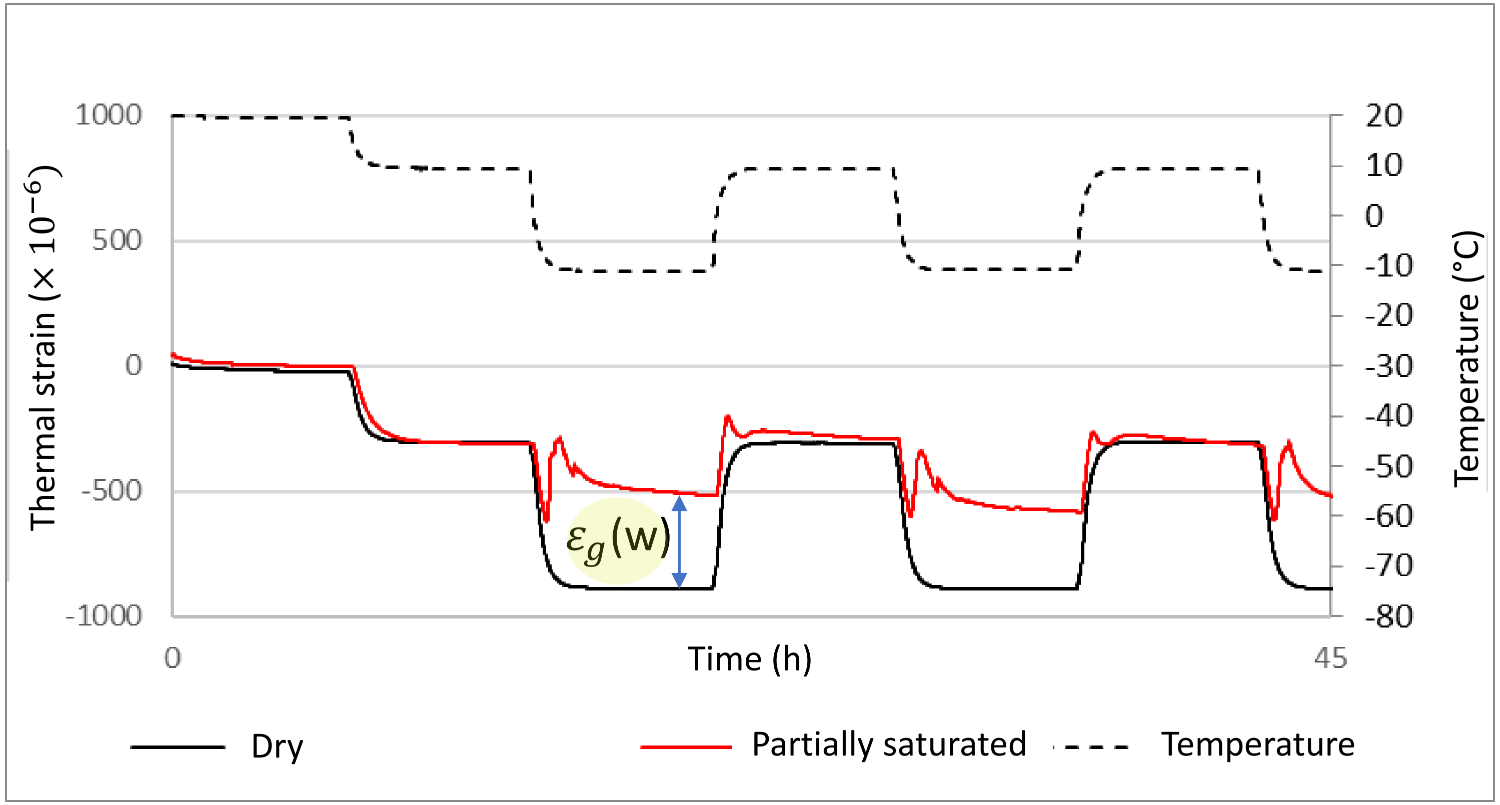
About the partially saturated structure (figure on right)

- Strains measured by the 2 couples of gages evolves in the course of the temperature cycles
  - Values quite similar during cycle #1 but different at cycle #2 and #3
  - Could be explained by the development of vertical cracks in direction T close to couple of gages #1

Characterization of the swelling strain in the lab. for ESG10

Cooling stress in free stress conditions (CTFS)





- CTFS tests performed for dry and partially saturated AC materials
- Difference in strain measured at the lower temperature plateau provides ε_g
- Here, ε_g of the order of 300 $\mu strain$ for a water content of about 5% (saturation approximately equal to 60%)

  → Value used in the simulation